The Ecology of Forest Fires

By Terence P. Dawson, Natalie Butt and Florence Miller

In many ecosystems, fire is part of the natural regeneration process, stimulating the germination of certain species, clearing space for the invasion and growth of others, and releasing a periodic flush of nutrients into the soil. Yet tropical forests were until recently considered incapable of burning. Their ground layers were found in tests to be too moist to sustain fire, and it was assumed that this was always the case (Uhl, 1998). However, the remains of charcoal in tropical forest soils are testimony to the fact that in the post, fires have had catastrophic effects in tropical forests. Today, vegetation fires are affecting primary and secondary tropical forests. In 1983, three million hectares of lowland rainforest were destroyed in Kalimantan alone (Whitmore, 1998); in 1997/98, around 4.66 million hectares of forest were impacted across Southeast Asia (Rowell and Moore, 1 999).

Southeast Asia is particularly susceptible to wildfire. The World Fire Web's global fire maps show where most of the world's vegetation fires occur: Southeast Asia has more fires than Australia, and is third only to Africa and South America (Environmental News Network, 1999). Mainland Southeast Asia, which is more strongly seasonal and less humid than many parts of insular Southeast Asia, favors the use of fire as a land management tool and supports more fire-prone ecosystems. Wildfires, those fires not meeting their management objectives and therefore requiring suppression, are consequently common (Grégoire et al., 1996).

The greater numbers of fires in tropical forests are not solely the result of natural factors and conditions. Primary forests that have been relatively undisturbed are fairly resistant to fire, and an active fire front in an intact closed canopy forest is unimpressive. Except for tree-fall gaps and areas of unusual fuel structure, fire will spread as a thin, slowly creeping ribbon of flames a few tens of centimetres in height (Cochrane and Schulze, 1998), or it will spread through the canopy (Kimmins, 1992). Over much of the burned area, the fire will consume little besides leaves and leaf litter However, it only takes a bit of open canopy, such as that caused by light clearance and/or drought, to tip the balance from a fire-resistant to a fire-ready forest. And, while first-event fires in primary forests tend to result in relatively little damage, fires following clearance can be much more harmful.

In general, fire has followed clearance in tropical forests. Logging per se does not cause fires, but the indirect effects have been, and continue to be, devastating. Under 'natural' conditions, a large proportion of the heat generated in a fire may be released high above the ground as the fire travels through the canopy - most combustible fuel is in the standing (live and dead) trees. With a closed canopy, little light reaches the ground layers of tropical forest, and there is little vegetation to burn. Thus, the fire on the ground is often much less severe and consumes relatively little of the forest floor other than leaf litter. In areas of open canopy (normally created through clearance), however, all the fuel and the heat energy released are on or near the ground. Much or the entire forest floor may be consumed and heat damage to the upper mineral horizons of the soil may occur.

Fire danger is increased by clearance for a number of reasons. First, it produces quantities of dead, flammable material. Second, the opening up of the canopy allows light to reach the ground layer of the forest, encouraging understorey vegetation to grow. The gross, creeping vines and small shrubs that result all pose fire hazards. Finally, the gap created by clearance lets in wind, which reduces humidity, dries out dead materials, and encourages the spread of fire (Bowen et al., 2000).

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If the forest re-burns within a few years of the initial fire, the fires will be much worse. The first fire opens up the canopy such that favorable conditions are created for a second fire (Uhl, 1998). Dead material produced by the first fire poses a fire hazard until completely decomposed, and the death of trees in the fire produces gaps in the canopy, leading to problems associated with increased light, wind and dryness described above. Thus, in recurrent fires, flame length, depth, spread rate, residence time and fireline intensity are all significantly higher. Cochrane and Schulze (1998) predict that a second fire will kill 40% of remaining stems. In other words, first fire events are capable of setting a positive feedback system in motion that could lead to the progressive impoverishment and degradation of vast expanses of tropical forest (Figure 1). No other disturbance in tropical forests has this self-reinforcing character with the potential to occur on such a grand scale (Uhl 1998).

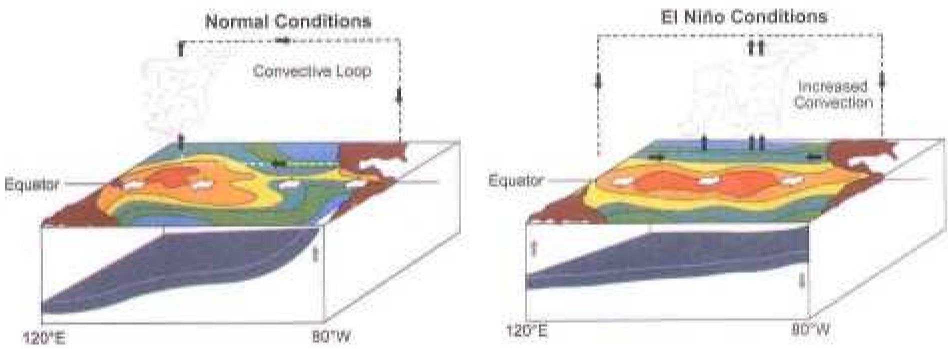
Figure 1: Positive feedback system associated with forest fires

Influence of El Niño on the Forest Fire Regime

While forests that have undergone patchy clearance are susceptible to fire, it is weather conditions that tend to tip the balance. During long periods of drought, forests dry out, particularly the dead wood and material on forest floors produced by clearance. Those wishing to clear the forest for agricultural purposes frequently take advantage of the dry conditions to set fires. Unfortunately, fires set towards the end of a dry season, and particularly towards the end of prolonged drought, have a tendency to burn out of control, quickly turning from managed fires to wildfires.

Prolonged droughts affect South-east Asia with relative frequency, governed largely by the El Niño Southern Oscillation (ENSO). El Niño is a reversal of the ocean-atmosphere system in the tropical Pacific. It has important consequences for weather around the globe and, in Particular, tends to cause drought in the West Pacific.

In normal, non-El Niño conditions (Figure 2), the trade winds blow westwards across the tropical Pacific. These winds pile up worm surface water in the west Pacific, so that the sea surface is about half a meter higher at Indonesia than at Ecuador. The sea surface is about 8^{o}C higher in the west than the east Pacific. Rainfall is found in the rising air over the warmest water, and the east Pacific is relatively dry.



Schematic diagram of normal and El Niño conditions in the Pacific Ocean

During El Niño *(see right hand panel of the schematic diagram)*, the trade winds relax in the central and western Pacific. Worm water and air currents no longer flow westwards with the some strength, and the warmest waters move eastward, away from Southeast Asia and towards the central Pacific. Rainfall follows the worm waters, with associated flooding in Peru and drought in Indonesia and Australia (Pacific Marine Environmental Laboratory).

El Niño events tend to occur every two to seven years, and lost for a period of twelve to eighteen months at a time. Analysis of data by the US National Oceanic and Atmospheric Administration (NOAA) from the 10 strongest El Niños of the past century has shown that 'they are occurring more frequently, and that they are becoming progressively warmer' (Rowell and Moore, 1999). Whether or not this change is directly linked to global worming remains uncertain. However, the onset and decline of the 1997/98 El Niño event was predicted accurately by scientists from the Max Planck Institute in Germany, and the model they used incorporated greenhouse-gas concentrations. It seems likely that the rising temperatures caused by climate change could cause El Niño to become more frequent and with increasing intensity. Further, evidence has shown that large-area forest fires load clouds with large numbers of smoke particulates, which condenses the accumulated water vapour and suppresses rainfall, hence tropical fires exacerbates drought events (Lecitch et al. 1992).

Fire Impacts on Biodiversity

The forests of the wet tropics are one of the richest in biodiversity of any ecosystem on earth (Meffe and Carroll 1977). Tropical rainforests typically occur in areas in which even the driest month of the year has at least 10 cm of precipitation; this is the reason for their abundant, lush vegetation. The annual dry season, although noticeable, is neither dry enough nor long enough to cause the trees to drop their leaves. And indeed, until the Borneo fires associated with the ENSO event of 1982-83, it was thought that undisturbed rainforests simply could never dry out enough to burn.

Southeast Asia (especially Indonesia and Malaysia) has some of the largest areas of rainforests in the world, dominated by frees of a single family, the Dipterocarpacece, which includes many valuable timber species that are a mainstay of the tropical timber trade (Whitmore, 1984). Commercial logging is thus one of the chief causes of deforestation in the Southeast Asian tropics.

Another distinctive feature of Southeast Asian rainforests is their large area of peat swamp - wet forests in which organic matter has accumulated for thousands of years without decomposing, resulting in thick peat soils which can reach 20 m in depth. These soils are usually poor in nutrients and are extremely difficult to convert to productive agriculture, but, if properly managed, can often produce valuable Dipterocarp timbers (Whitmore 1984). Recurrent fire events will reduce soil fertility, as the opening of soil surfaces will damage the soil structure. In the next rainy season, the soil particles and ash will be leached by the rainfall into water-courses and estuaries resulting in a decline in water quality.

An assessment of the impact of fires on biodiversity will take months or years, but there are already news reports of alarming consequences for endangered species. Small, slow-moving animals (small mammals, herpefauna) and insects are most likely to be killed outright by fires. During the fire incidents in Kalimantan, it was estimated that 120 adult and 60 juvenile orangutans died in the fires. Another 29 orphaned and displaced orangutans had been found in villages and alongside the roads after escaping from the forests, probably in search of food and water (World Wide Fund for Nature, 1997). Animals that are driven from their normal habitats because of fire become vulnerable to hunting and exploitation by local people, especially when the fires reduce their usual sources of food income. WWF has also noted that 11 protected areas were burnt in the islands of Sumatra, Kalimantan, Irian Jaya, and Java. The areas in which fires are common include the habitats of such critically endangered species as the Javan and Sumatran rhinoceroses and the Sumatran tiger (WWF, 1997).

According to the World Conservation Monitoring Centre, the fires in Indonesia are now threatening at least 19 protected areas, all inter-national important, including a World Heritage site (Ujung Kulon in Wetland (Berbak in the Sumatra) and the Tanjung Puting Biosphere Reserve in Kalimantan. A large number of endangered species is in the path of the fires. Individuals of territorial species fleeing unburned areas can encounter egression from the residents and may be killed or injured in fights. Animals with very specific food, habitat, shelter and climatic requirements are most at risk during the post-burn period. Fruit-eating animals and birds such as the orangutan and hornbill species are especially affected, because the trees that they predate on take many years to mature and fruit. These two species, like many others, are already under tremendous pressure from severe habitat loss. Finally, the loss of key organisms, such as pollinators and decomposers, can significantly slow the recovery of forest ecosystems although interestingly, large herbivorous may actually increase in numbers after a fire event due to the subsequent flush of new vegetation.

Conclusion

Clearance, drought and human activity combined produce the necessary conditions for serious fires in tropical forests. Clearance results in the production of dead, combustible materials (fuel), allows sunlight to reach the forest floor (reducing humidity and encouraging the growth of understorey vegetation), and increases the wind flow through the forest, which both dries out the area and helps to spread fire. During El Niño periods, those people with an interest in clearing areas of forest - be they plantation workers, agriculturists or slash-and-burn cultivators - may take advantage of the dry conditions to set fires. Without firebreaks and careful control over burning (and even with control, under very dry conditions), such fires can quickly become wildfires, causing great damage to healthy forest in the vicinity and associated biodiversity. Forests that have been degraded by human activity or a previous fire event become more susceptible to second or subsequent fires with increasing severity.

More frequent El Niño events do not give forests an opportunity to recover from prior burn events. Large areas of fire-degraded forests may take decades if not centuries for complete regeneration due to loss of keystone species, paving the way for future fires.

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